VIRTUAL ENVIRONMENTS FOR HUMAN CENTRIC RESEARCH

by

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A THESIS

Presented to the Department of Computer and Information Science
and the Graduate School of the University of Oregon
in partial fulfillment of the requirements
for the degree of
Master of Science

June 2011

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Title: Virtual Environments for Human Centric Research

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THESIS ABSTRACT

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June 2011

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Conducting field studies for human centric research often demands a significant amount of time and effort. Virtual Environments (VE) can be a potential alternative to reduce such requirements and help scale the field studies. However, we may experience a performance difference between (1) a virtual trial, and (2) a field trial of the same study. To learn under what circumstances a VE can successfully replace a field study and when it fails, this thesis describes a route-following experiment that compares the participants' performance between a simple VE and a field setup. The experiment results unveil that there is a significant difference in performance between a physical and a virtual setup for more challenging navigational tasks, whereas no significant difference is observed for simpler tasks. This finding encourages us to replace a less challenging field study with a simple VE, and explore the possibilities for a complex one.

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ACKNOWLEDGMENTS

It is a pleasure to thank those who made this thesis possible. I owe my deepest gratitude to my research advisor, Dr. Stephen Fickas, whose kind encouragement, timely advice, brilliant insights and gentle guidance made this thesis a possibility. There are not enough kind words to express my appreciation for his involvement in my education and research.

I wish to thank Dr. Christopher Wilson for stepping into the position of committee member and believing in my ability to complete my research and produce this thesis.

I want to express my gratitude to Xiangkui Yao for his kind support through his knowledgeable advice that went into this thesis.

Finally, I would like to thank my family and friends for the unbelievable amount of support and love shown to me throughout my graduate school journey.

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CHAPTER I

INTRODUCTION

Running experiments in virtual environments (VE) can benefit researchers in several aspects. A virtual setup can save researchers a considerable amount of time by shrinking the study completion time as field studies can take from months to years to complete. As one example, a navigational field study [1] carried out by S. Fickas et al. at the University of Oregon took a full year to run twenty human subjects. A VE setup can also reduce other efforts required to run a field study. For example, running a navigational experiment, with those with a disability, needs precaution for the safety of the subjects. Darken et al. [2] suggests that “virtual reality circumvents potential obstacles of mobility impairment or physical fatigue (particularly when studying walking routes), and because of ‘time compression’ it can allow more to be achieved within a given time period”.

When considering setting up a study in a virtual environment, there remains the question of whether or not the participants will perform similarly as in the real world under similar circumstances. In the past, several research studies [3,4,5] were conducted to compare physical and virtual navigation performances. A few of these studies reported differences, whereas other studies confirmed similar performances in both setups. We may hypothesize that this dissimilarity in findings of these studies is caused from the unlikeness of virtual environments (e.g. Desktop, Immersive) used in these studies, and the variation (in difficulty) of the tasks chosen to compare participants’ performance. However, no particular study was found during the literature review phase of this thesis that attempted to answer: under what circumstances (e.g. what sort of task difficulty, what type of virtual environment) we may expect differences or similarities in performances between a virtual and a physical setup. As a result, in this thesis, an experiment was designed to compare participants' performances to report any difference or similarity between these two setups on different circumstances.

A simpler, 2D Desktop, virtual environment was chosen to compare participants' performance as immersive virtual environments are often costly to setup for non-commercial experiments. An indoor setup was chosen to run the study as indoor navigation is often found challenging because of the nature of the landmark arrangements and compact spatial setup. At times, participants were intentionally given incorrect directions. Running the study in an indoor setup given challenging directions was helpful to create different degrees of task difficulties and compare participants' performance in those circumstances, both in the field and in the VE setup. Error detection performance of human subjects in challenging navigational directions was compared between these two environments. Again, this is because no study was found that compared navigational performances given bad directions. The only exception is a recent study [6] that investigated the getting lost behavior of acquired brain injured population; however, no virtual environment was used to compare with the field results with the virtual setup results.

In particular, a study was performed in this thesis to answer the following questions to report any differences between physical and virtual setup:

i) *Are there differences in error detection and correction behavior between a physical and a matched virtual setting*?
ii) *If there are differences or similarities, can they be correlated with task difficulty?*

The results of the study confirm that there is a significant difference in error detection and correction performance between a field and a simple virtual setup for more challenging navigational tasks, whereas, for simpler navigational tasks, no significant difference is observed. This is the primary contribution of this thesis and hopefully this finding will encourage researchers to replace a less challenging field study with a simple VE, and explore the possibilities for a more challenging one.

CHAPTER II

BACKGROUND

This section provides the background information that has shaped to perform this thesis. First presented is a study that investigated the getting lost behavior of travelers with acquired cognitive impairment. Next introduced is another study to compare the cognitive mapping using physical and virtual navigation. Finally, covered are the PC-RE (personal and contextual requirement analysis) framework and a supporting study that investigated individual differences and personal requirements while accessing a mobile phone based navigational assistant.

2.1. Getting Lost Behavior Study

R. Lemoncello et al. [7] conducted a study in downtown Springfield, Oregon to investigate the getting lost behavior of travelers with acquired cognitive impairment (ACI). The motivation of this study was to recognize travel problems (lost, anxious, and confused) with ACI population and then try to solve it in the field. In particular, this study was designed to answer the following research questions.

i) Are there differences in how participants with ACI solve navigational challenges compared with age, gender, and education-matched non-injured control participants?

ii) Do individuals with ACI demonstrate greater delay and less planning compared to age, gender, and education-matched non-injured peers when asking for assistance due to a missing step with written navigational instructions?

iii) Are there differences in preference for re-orientation by telephone between participants with or without brain injury?

iv) Are there differences in how individuals with ACI or non-injured peers describe their current location to an unfamiliar phone assistant at a remote location?

v) Are there differences in the quality of potential solutions to on-route navigational challenges described by individuals with ACI compared to non-injured peers?

Participants with cognitive impairment and matched control without impairment were asked to follow a set of written directions (with some incorrect steps). Intentionally incorrect instructions were included to identify the getting lost behavior of the participants. Subjects were provided with always on ear bud (with cell phone in pocket) to communicate a researcher (phone-helper) for assistance. Subjects were required to describe their location and problem to the phone-helper to get assistance. Phone-helper followed a general script for helping a subject problem solve. At the same time phone-helper asked the subjects for their solution of the problem (as a part of the general script). Two other field researchers followed the participants and kept field notes. Conversions between subjects and phone-helper were audio recorded. All these data were used to describe and investigate possible group difference in how participants described their current location, generated potential navigational solutions, and opinions about the use of a cell phone for pedestrian navigational assistance.

Results from statistical analysis and observations unveil the following interesting findings.

- Statistically significant overall difference was found in how participants with ACI solved navigational challenges with matched non ACI control. Participants with ACI were more likely to request for assistant (10/18) comparing to control participants (6/18) at the missing directions. Similarly at the hidden street sign, 6 ACI participants requested assistance where as only one control participant needed assistance.

- Control Participants demonstrated greater planning ability and were able to anticipate errors at the time of missing instruction where as participants with ACI generally could not anticipate the error or waited to ask for assistance.

- For the control group, 97% (29/30) of the location description were clear and accurate where as 23% (11/47) of the descriptions provided by the ACI participant provided vague and 9% (4/47) were inaccurate.

- Participants with ACI gave more vague, inaccurate and non-solution of the problem comparing with the control when asked by the phone-helper. At the missing instruction, control participants provided 100% (15/15) reasonable solutions where as 31% (5/16) solutions provided by the ACI participants were vague or inaccurate and 13% (2/16) were non solutions.

In summary, results of this study confirmed the prevalence of navigational challenges faced by brain injury survivors, even on a short pedestrian route. Participants with ACI demonstrated significantly greater on-route navigational challenges -- more frequent errors and hesitations -- than matched controls. Participants with and without ACI exhibited different types of problem solving approaches. The ACI group requested assistance over the cell phone more frequently than controls, and required more attempts at re-orientation with concrete, salient directions in order to re-orient in the field. Participants in the control group anticipated errors with greater frequency than those with ACI.

2.2. Cognitive Mapping Comparison Study

At the University of Oregon, X. Yao [8] conducted a study to compare cognitive mapping using physical navigation and virtual navigation to see whether virtual navigation can work as effectively and efficiently as physical navigation in the real environment to provide special knowledge. Xiangkui built a two dimensional (2D) slide show style virtual environment (VE) using 2D photos of the University of Oregon Knight Library. One group of participants explored the Knight Library first floor physically whereas the other group used the virtual simulation of the similar area of the Knight Library. After 10 minutes of exploration inside the Knight Library first floor, both the physical and virtual group participated in three different tests - Landmark knowledge test, Route knowledge test and Survey knowledge test by answering several question designed for these tests. Participants were scored for each correct answer.

In this study, no statistical significance difference was reported between physical and virtual navigation at these three levels of cognitive mapping for special knowledge acquisition - landmark, route and survey knowledge. However distribution of data unveils that all these three levels of cognitive mapping, physical group performed better than virtual group. Another interesting finding of this study was that some virtual group participants navigated in clear systematic order and scored higher than those who randomly explored the area and got lost frequently. Based on this finding of navigational pattern, this study suggested that we might be able to predict participants' cognitive mapping performance in virtual environment based on their pattern of navigation. This information of individual differences can be useful for designing personalized virtual environments to achieve optimal performance of cognitive mapping.

2.3. Personal Requirement Analysis Study

PC-RE [9] is a framework for personal and contextual requirements analysis. The motivation for the framework is that considering just general functional or non-functional requirements of a software system is not always enough. Individual characteristics and personal goals, and the effect of time and context on personal requirements should also be considered. The framework, as shown in Figure 1, has three layers: general requirements, individual user characteristics, and personal goals. At each layer, requirements vary over location and time.

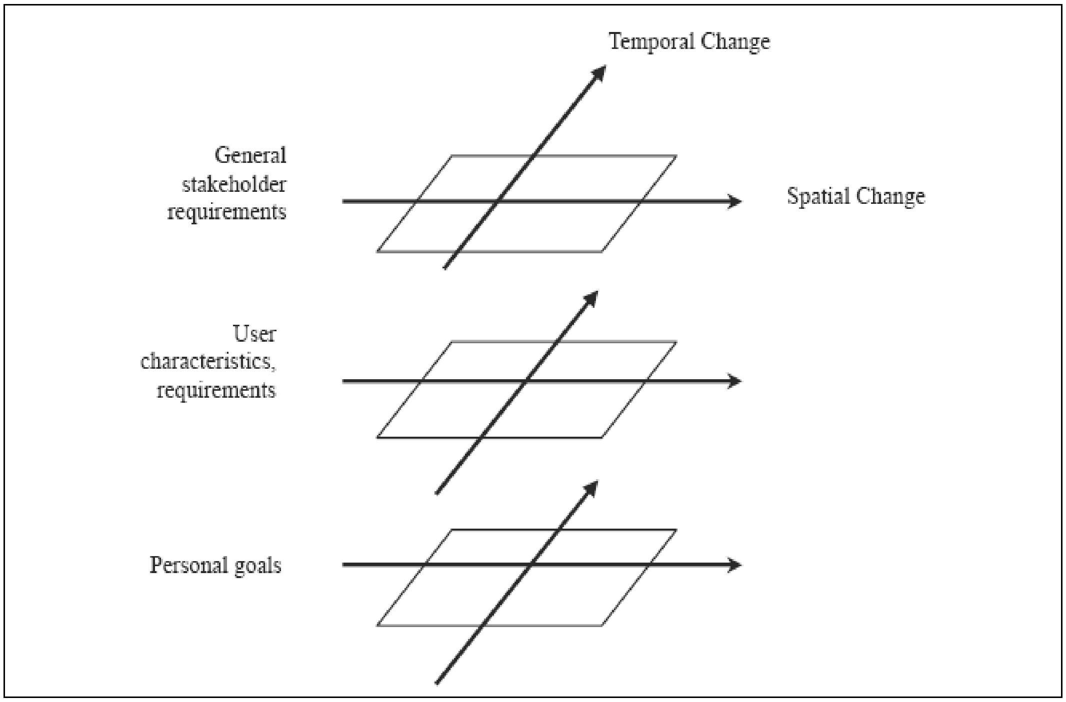


Figure 1: PC-RE framework

Five graduate researchers at the University of Oregon conducted a small study aiming to investigate individual differences and personal requirements while assessing a mobile phone based navigational assistant. The android mobile application was developed to provide a way of storing geo-tagged photos taken by a traveler and audio descriptions of the places of interests. Travelers could also select boundary of travel area and get warnings if boundary was crossed while exploring an area. A virtual environment was also constructed using Google's street view API to test the application. Six gender balanced participants were recruited and asked to explore the area of 3x3 square blocks in downtown Eugene for the physical trial. A similar 3x3 square block of San Francisco China town was chosen for virtual environment trial using Google's street view. Participants were given 30 minutes to find at least one place that serves food in each block. Researchers accompanied the participants during trials and took field notes. The experiment was designed to see whether there are similar individual differences in navigational performance while assessing a phone based navigational assistant in the field and in a similar virtual environment.

No statistical test was performed because of the small number of (6 participants) sample size. Based on the field and virtual environment observations performed by the researchers, it was clear that all the subjects performed better in physical environment (found more food serving places accurately) than virtual environment. However, some subjects were found using systematic approach (using memory and map in the phone) to explore the whole area in field whereas often found lost in virtual environment. Again some subjects were traversing same block in virtual environment again and again without noticing. Because of time limit, some subjects only looked at one side of a road to find a restaurant whereas it was natural to look at both sides of the road in the physical environment.

2.4. Conclusion

The three studies presented in this section, paved the way to perform this thesis to understand the circumstances where a virtual environment can successfully replace a field study and where it fails. Giving intentionally incorrect directions to test error recovery performance was adopted from the getting lost behavior study presented in this section. The cognitive mapping comparison study over virtual and physical environment was a true encouragement for this thesis. Though the result was not significant but some success encouraged conducting this thesis to start with a simpler VE to compare navigational ability. Understanding similarities and dissimilarities in personal level also help to better understand the circumstances when a virtual environment is a good fit for replacing a field study. That was exactly what was found from the personal requirement analysis study.

CHAPTER III

RELATED WORK

3.1. Virtual Environments

Virtual reality (VR) is a way to interact with a computer-simulated environment. The real world environment can be represented with a computer programmed display to allow human users to interact and explore in the synthetic world that mimics a similar region of the real world environment. The value of virtual reality applications for risky situations such as flight training [10] or teaching surgeons complex procedures [11] is well recognized. Training of dismounted soldiers also benefits from Virtual Environment [12] by gathering special knowledge and then transferring to real world.

A less common use of virtual reality is in navigational research and in the past years researchers started looking at this domain. Witmer et al. [13] were among the first to show that a virtual environment could be useful for spatial knowledge acquisition. Darken et al. [14] claims that this study [13] effectively provided optimism that the technology could work for this purpose – but not how well or under what conditions. Darken et al. [2] studied how a virtual environment might be used as an augmentation to traditional familiarization methods. This study was unique of its kind. It required the participants to plan their own routes rather than practice a given one. This served to develop survey knowledge since alternative routes must be explored. It was also attempted to introduce individual experience as a factor in addition to spatial ability.

Since the task was specific to a particular domain, experience on these types of tasks should have an effect.

Running experiments in a virtual environment can also reduce the effort required in real world experiment. For example, running a navigation experiment, with those with disability, needs a lot of precaution for the safety of the subjects as experiments of this kind require physical movements of the participants. Also the experiment might be hampered because of the immediate sickness or unexpected accident caused from wrong movement of the participants. Thus for running an experiment for human navigation tasks, virtual environments can be alternative to the real world experiment set up, and can avoid these risks. Darken et al. [2] similarly suggested that virtual reality also circumvents potential obstacles of mobility impairment or physical fatigue (particularly when studying walked routes), and because of 'time compression' it can allow more to be achieved within a given time period.

3.2. Virtual and Real World Navigation

With the improvement of technology, researchers gained the capability of testing the spatial ability in a virtual world. However, little research has been conducted to understand whether a VE performance can predict real world performance or not and amongst the measures used [15] what measures are most predictive. Does experiencing a synthetic environment lead to similar behaviors [5] a person would have in the real world under similar circumstances?

A study [16] has been performed by McKinnon et al. to compare the sense of presence in a virtual world with the sense of presence in the real world while exploring the virtual environment. The result from this study, lead to a preliminary and interesting theory that a person's overall sense of the world actually increases slightly when put into a virtual environment. How about when performing navigational tasks in VE that models a portion of the similar real world?

David Waller et al. [17] used virtual environment to access the relative accuracy and precision with which people estimate directions among unseen landmarks. Four different non real (immersive VR, desktop VR, paper-panorama and directions circle) environments were compared with real environment setup of the experiment. In this study, it was found that neither the immersive VR nor the desktop VR setup was significantly different than the real setup for absolute pointing error of the participants.

In another study, David Waller [18] has shown how by incorporating a dynamic first person simulation of navigation, a very simple desktop VE can be used to predict and understand the cognitive abilities that are involved in large-scale environment behaviors. Errors and decision latencies calculated were found significantly related to participants' ability to point to known locations in the real world.

Looking at several experiments Darken et al. [14] hypothesized how spatial knowledge might be acquired over time depending on the apparatus used. If we closely look at Figure 2, we can see that for shorter amount of exposure time, VE outperforms real environments for special knowledge acquisition and VE is close to real environment performance if longer exposure time is allowed, depending on the type of VE used for the experiment. Maps are best for short term events, but the real world or virtual environments with training interventions (VE+) are best over time. (Courtesy -Darken and Patterson, 2001)

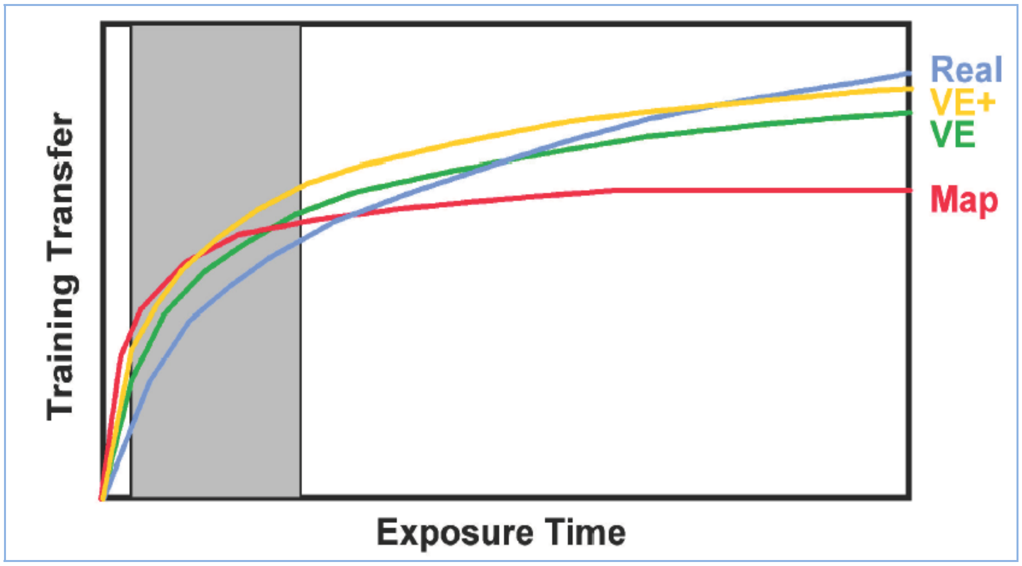


Figure 2: Spatial knowledge acquisition over time depending on the apparatus used

In a study [19] on the use of virtual environments for acquiring configurational knowledge about specific real-world spaces, three different types of VE were tested against the real world. Participants explored in three different VE (head mounted display, desktop display, and 3D model of space) and real world and, then were asked to estimate the location of given landmarks for test. Results obtained from each of these four conditions were found roughly same.

Arthur et al. [4] performed another study for navigation training in virtual environments. This study unveils that special knowledge acquisition form navigation in VE can be similar to actual navigation when viewing condition is unconstrained.

Ruth Conroy [20] in her PhD dissertation on Spatial Navigation in immersive virtual environments tried to investigate whether we move trough virtual worlds in a manner that is analogous to our behavior in the real world. In one experiment he compared the virtual navigation data to the movement observations of people made in the real visit of the indoor setup of the London Tate Gallery. This experiment found a strong statistical correlation between these two data sets concluding, in the pattern of pedestrian movement there is relationship between real and virtual space.

Joanne Lloyd et. al. [3] performed a study of route learning task and compared the performance of the participants in a VE (driving simulator) with the real world participants' performance. The result indicated equivalence between the real and virtual environments, with comparable error rates and no differences in strategy preferences.

3.3. Summary

A few of the studies presented in this literature review section reported differences, whereas other studies confirmed similar performances in both the physical and virtual setups. We may hypothesize that this dissimilarity in findings of these studies might be because of the unlikeness of virtual environments (e.g. Desktop, Immersive) used in these studies, and the variation (in difficulty) of the tasks chosen to compare participants' performance. Surprisingly, no particular study was found that attempted to answer, under what circumstances (e.g. what sort of task difficulty, what type of virtual environment) we may expect performance differences, and when we may expect similar performances between a virtual and a physical setup. This confirms the requirement of performing further research to answer this particular research question. The route following study presented in the next chapter is designed to compare participants' performances to report any difference or similarities at different circumstances.

CHAPTER IV

ERROR RECOVERY PERFORMANCE IN PHYSICAL AND VIRTUAL ENVIRONMENT

4.1. Methods

The study presented in this thesis was designed to see where a simple virtual environment (VE) for navigational tasks breaks down in terms of a simulation of physical space. This study is expected to describe the circumstances where a simple VE is a good fit for the field assessment, and where we may expect different results than the field. We chose to compare the error detection performances of human subjects in challenging navigational directions between these two environments.

4.1.1. Participants

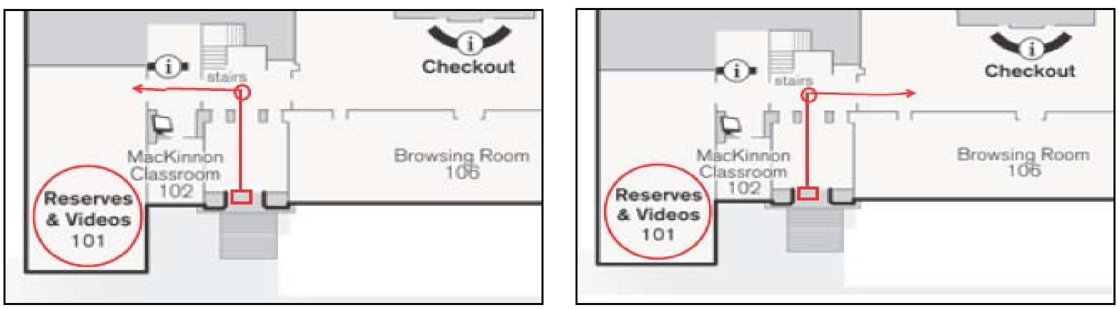
Two gender balanced group of 14 paid subjects (28 in total) were randomly selected to participate in this experiment. The mean age of the participants of the physical navigation group were 22.29 years (SD=5.09), and the mean age of the virtual navigation group was 21.43(SD=2.90) years. All of them were University of Oregon students, and were completely unfamiliar with the areas of the Knight Library where the trail happened. The unfamiliarity was confirmed with each participant before the trial. All the participants who participated in physical trial were physically capable of participating in the experiment. Virtual Knight Library participants had no problem of using computers.

4.1.2. Materials

The experiment was designed to be conducted in two parts. One group of participant physically navigated in the first floor of the University of Oregon Knight Library. Other group navigated through virtual simulation program of the Knight Library first floor using a slide show style program in Dell Inspiron-1501 laptop computer with 15” monitor (1280x800), 2.0GHz CPU and 1.87GB of RAM. Slide show style program was constructed by a Java program that could present 2D photos of the Knight Library first floor (indoor). In the virtual environment, participants could use the “Left”, “Right”, “Forward”, and “Turn Around” buttons to navigate, as shown in Figure 3. They could also use arrow keys of the keyboard to navigate through the virtual environment.

Figure 3: Virtual Knight Library program

Participants will always see the picture of the part of the knight library first floor based on the current orientation. Only by hitting “Forward” button (or Up Arrow key) they can move to the next choice point in front of them. “Left” and “Right” buttons will make them turn 90 degrees, and the “Turn Around” button (Down arrow key) will make them turn 180 degrees and orient them to the opposite direction of their current orientation. Figure 4, Figure 5 and Figure 6 show (a) the real routes and directions and (b) the routes and directions given to the subjects to follow for each task. Task1 was moderately difficult navigational task with one choice point with a wrong direction. Task2 was the easiest with a single choice point and a missing direction. Task3 involved two choice points with one wrong direction, and no visual cue made it the hardest task to perform.



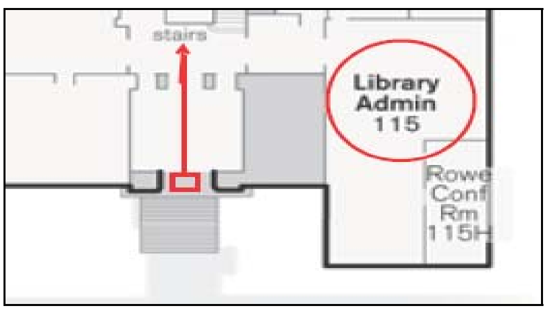
(a) **(b)**

Correct route directions for Task1
1. Walk straight through the gate in front of you
2. Turn Left
3. Walk to the "Reserve and Videos" section
4. Stop as you reach to the "Reserve and Videos" section

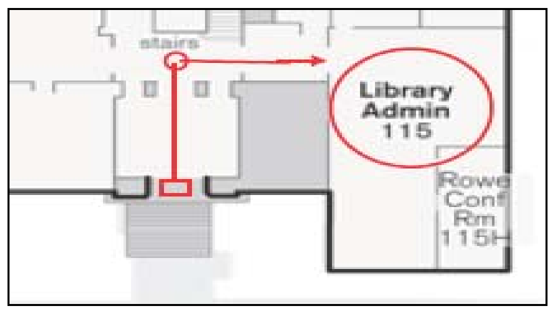
Directions given to the participants for Task1
1. Walk straight through the gate in front of you
2. Turn Right
3. Walk to the “Reserve and Videos” section
4. Stop as you reach to the “Reserve and Videos” section

Figure 4: Task1 route and instructions - To reach at the Knight Library video section

There was a visual cue (direction sign for the video section) for Task1. Similar to Task1, there was a visual cue (direction sign for the library admin section) for Task2. After executing the first instruction, the absence of the next instruction to guide which direction to turn, makes the cue more obvious to look for. The cue for Task1 was hard to follow because one wrong direction was given intentionally after the first direction was executed. Participants could easily miss the cue just by following the wrong instruction. For Task3, the cue was less obvious (no direct visual sign), and participants had to use their sense that following the wrong instruction will lead them to the outside of the library, and it was less intuitive to find the document center. For all these three tasks, same cues were used for both the physical and the virtual environments.



(a)

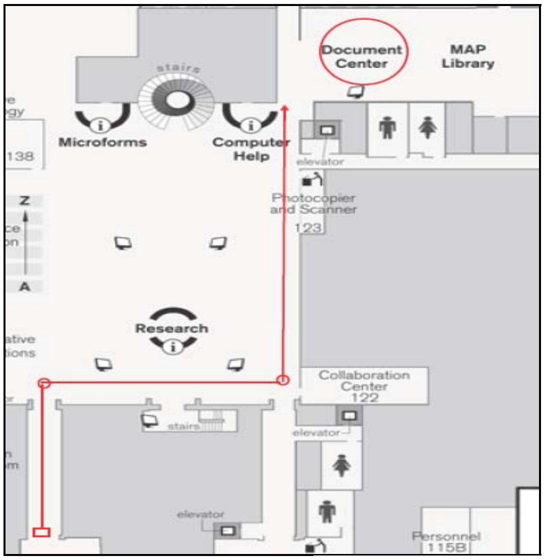


(b)

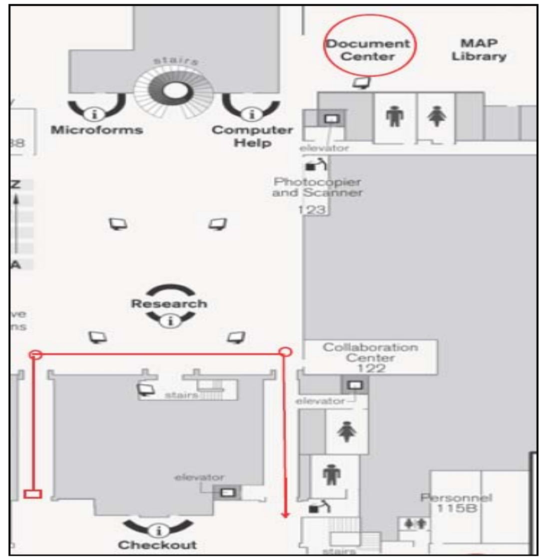
Correct route directions for Task2
1. Walk straight through the gate in front of you
2. Turn Right
3. Walk to the "Library Administration" section
4. Stop as you reach to the "Library Administration" section

Directions given to the participants for Task2
1. Walk straight through the gate in front of you
2. Walk to the "Library Administration" section
3. Stop as you reach to the "Library Administration" section

Figure 5: Task2 route and instructions - To reach at the Knight Library admin section



(a)



(b)

Correct route directions for Task3
1. Walk to the end of this corridor
2. Turn Right
3.Walk straight to the "Collaboration Center"
4. Turn Left
5. Walk towards "Exit"
6. Stop as you see the "Document Center"

Directions given to the participants for Task3
1. Walk to the end of this corridor
2. Turn Right
3.Walk straight to the "Collaboration Center"
4. Turn Right
5. Walk towards "Exit"
6. Stop as you see the "Document Center"

Figure 6: Task3 route and instructions - To reach at the Knight Library Document center

4.1.3. Procedures

At the beginning of the experiment, each participant was given standardized written instructions describing the procedure and the goal of the experiment. The researcher also asked questions and provided clarifications to ensure comprehension. Participants had to participate in three route-following tasks inside the University of Oregon Knight Library. Prior to begin a task, each physical navigation participant was taken to the starting point of the route. Participants of the virtual navigation group completed the same three route following tasks using the computer simulated Knight Library. Every virtual navigation participant went through a training session, and navigated the virtual environment (different than the areas used in real trial) prior to the actual trial. Both the physical and virtual group participants were asked to follow a set of written directions to reach a target. Participants were requested to report any error in the directions they could find during the route following tasks to the researcher. Researcher accompanied the participants and took notes on participants' responses and other observations. During the trial, researchers did not make any conversation with the subjects. Subjects had to figure out the incorrect directions by their own. If a participant could not find the incorrect instruction or was taking unnecessarily long time, the researcher simply stopped him and took him to the starting point of the next task.

4.2. Results

Participants' error detection ability was scored on a 3-point scale (0 = unable to find error; 1 = could find error after following the wrong instruction; 2 = could find error before following wrong instruction). Scores of both groups (Physical and Virtual) for three different tasks were collected and listed along with each participant's gender and age in Table 1 (physical navigation group) and Table 2 (virtual navigation group).

The samples are independent, and the data are not normally distributed (Appendix E). Data was entered into SPSS 17.0. Categorical data analysis (Pearson Chi-Square) was performed (Appendix F) to report any significance difference in error detection performance between a physical environment (PE) and a virtual environment (VE) group of participants for any task.

Gender	Age	Task1	Task2	Task3
M	22	0	2	1
F	20	2	2	2
M	22	1	2	0
M	22	2	2	0
F	19	2	1	1
F	21	0	2	0
F	19	2	2	2
F	19	1	2	0
M	18	1	1	0
F	19	0	1	0
F	37	2	2	1
M	29	0	0	2
M	22	0	2	0
M	23	2	2	2
Mean	22.29	1.07	1.64	0.79

Table 1: Physical navigation group scores

Gender	Age	Task1	Task2	Task3
M	23	2	2	0
M	17	0	1	1
F	20	0	0	0
F	20	2	2	0
F	22	0	2	0
M	19	2	2	1
F	18	2	2	0
F	26	1	2	0
F	20	2	2	1
M	20	2	2	1
F	21	1	2	1
M	23	2	2	1
M	24	0	1	1
M	27	1	2	1
Mean	21.43	1.21	1.69	0.57

Table 2: Virtual navigation group scores

4.2.1. Physical and Virtual Environment Performance

We can see from Table 3, there is a significant difference (p = 0.042) in error detection and recovery performance of the participants between the physical and the matched virtual setting for Task3. However, no significance difference was found for Task1 (p = 0.910) and Task2 (p = 0.884). Task3 was comparatively difficult than Task1 and Task2. For Task3, participants had to follow a lengthy route which had more choice points than the other two tasks' routes. There was no visual sign to help correct the instructions, and therefore, the cue for detecting error in Task3 was difficult to use comparing to the other tasks.

Scoring Criteria	**Task1**		**Task2**		**Task3**	
	PE	VE	PE	VE	PE	VE
Could not detect error	5	4	1	1	7	6
Could detect error and proposed recovery *after* following wrong instruction	3	3	3	2	3	8
Could detect error *before* following wrong Instruction	6	7	10	11	4	0
Chi-Square Test (Pearson)	0.188		0.248		6.350	
***p* significance**	*p* = 0.910		*p* = 0.884		*p = 0.042*	

Table 3: Error detection ability by task and group

The Chi-Square test result listed in Table 3 confirmed a significant difference in error detection and recovery behavior of participants between the physical and the virtual group for difficult route following tasks (Task3), whereas, no significant significance difference was found for comparatively easier route following tasks (Task1 and Task2).

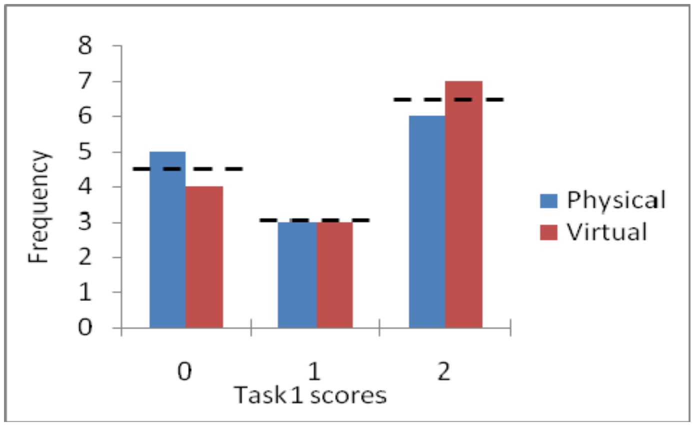
Finally, the conclusion of this experiment is that there exists a significance difference (p = 0.042) in error detection and recovery behavior of participants between a physical and a matched virtual setting for difficult navigational tasks performed in an indoor setup. However, no significant difference is observed for simpler navigational task.

4.2.2. Discussions

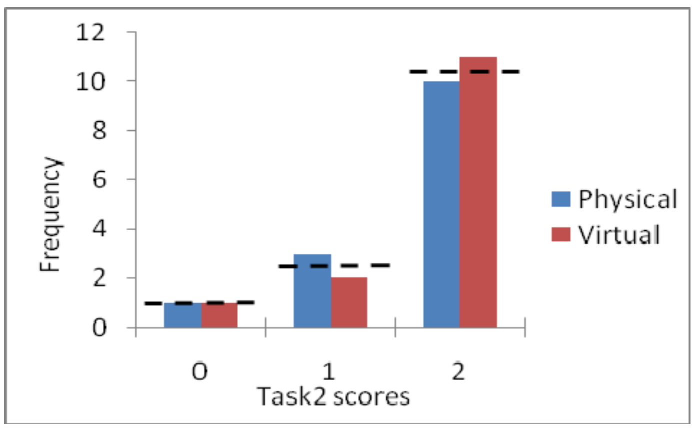
The results of this study confirmed a significant difference in error detection and correction performance between a physical and a simple virtual setup for difficult navigational task. However, no significant difference was observed for simpler navigational tasks. As shown in Figure 7, for simpler navigational tasks (Task1 and Task2), performance score distribution of physical navigation group is quite similar to the virtual navigation group. Again, both for Task1 and Task2, the performance distribution is close to the expected values shown with the dotted lines in Figure 7. However, this is not the case for the difficult navigational task, and we can see the noticeable difference in performance between the physical and the virtual setup and the distance from the expected values for Task3.

Task-wise mean comparison also supports the findings of the study. Mean score of virtual group for Task2 is quite similar ($\mu_{VE} = 1.69$) ≈ ($\mu_{PE} = 1.64$) to the physical group mean, and for Task1, it is little higher ($\mu_{VE} = 1.21$) > ($\mu_{PE} = 1.07$) than the physical group mean. However, for difficult navigational task (Task3) the mean score reflects something quite opposite ($\mu_{PE} = 0.79$) > ($\mu_{VE} = 0.57$). Moreover, for Task3, surprisingly none of the subjects in VE group could attain the highest score, whereas several subjects of the physical environment group scored full points.

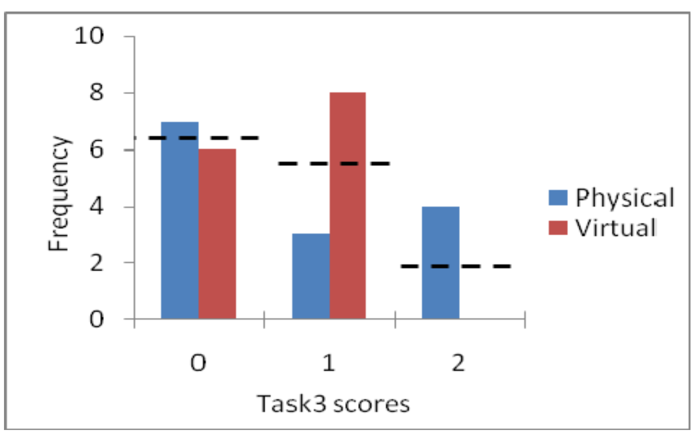
Findings of this thesis provides us insights, *for less challenging navigational tasks, simpler VE can produce similar results and encourages us to set up a simple and cost effective VE to help scale the field assessment for non commercial research.*



(a)



(b)



(c)

Figure 7: Score distribution of Physical and Virtual environments with expected values

Now, why the virtual navigation group's performance was different to the physical navigation group for the difficult task (Task3)? One reason could be the use of the 2D slide show style VE, which was probably not enough to percept special knowledge in difficult indoor setup. For Task3, VE group participants were also found more lost and confused about where they were at.

Moreover, for Task3, none of the VE participants were able to identify errors before following the incorrect directions and were lost more frequently. The 2D nature of the virtual environment that was used in this study has limited visual scope, which might have led the subjects to poor performance. Some participants also commented that "turning around" was tricky, and it was hard imagining a 3D environment though 2D. It is possible that for some participants, the training period was not sufficient. One more interesting finding is that in the VE setup, it took longer than in the PE setup to get back on track after participants were lost. Figuring out the correct way finding strategy perhaps took them longer time in the VE than the groups navigated through the PE. The cause of this might not be the dimensionality of VE, rather, the lack of natural representations of space in VE which is not enough to gather sufficient knowledge of space to recover errors in difficult indoor setup.

CHAPTER V

CONCLUSION AND FUTURE WORK

In this thesis, a study was conducted to see where a simple virtual environment breaks down in terms of a simulation of a physical space. Given bad directions in an indoor setup, the error detection and correction performance of the participants was compared in these two environments. Statistical test results confirmed significant difference in error detection and correction performance between physical and simple virtual setup for the difficult navigational task (Task3). However, no significant difference was observed for simpler navigational tasks.

For the difficult navigational task (Task3), it was found that, none of the subjects in the virtual environment group could attain the highest possible score, whereas some in the physical navigation group achieved the highest score. We may hypothesize that the limited visual scope of the 2D environment might be the reason. Still this needs to be addressed to understand, what restrained the participants who used the 2D slide show style virtual environment to attain highest scores for Task3.

Future works of this thesis include the improvement (of the dimensionality, user interface, etc.) of the virtual environment to see if there is still performance gap between a physical and a virtual setup for comparatively difficult navigational tasks. Some other interesting questions to address in the future are: Why do people get lost? What do they do to get back on track? How do they use the environment for problem solving? More interestingly, do we get similar performance of the participants both in a virtual and a physical setup? All these are important questions to explore, and would lead us to construct a better virtual environment to replace a field assessment for human centric research experiments. Finally, the concluding finding of this thesis is that, for simpler navigational tasks, we may set up a virtual environment to do the field assessment and achieve similar results. However, for difficult navigational tasks significant difference in performance is expected between a simple virtual environment and physical environment.

APPENDIX A

SANTA BARBARA SENSE-OF-DIRECTION SCALE

Sex: F M Today's

Date:________________

Age:_____

This questionnaire consists of several statements about your spatial and navigational abilities, preferences, and experiences. After each statement, you should circle a number to indicate your level of agreement with the statement. Circle "1" if you strongly agree that the statement applies to you, "7" if you strongly disagree, or some number in between if your agreement is intermediate. Circle "4" if you neither agree nor disagree.

1. I am very good at giving directions.

    strongly agree 1 2 3 4 5 6 7 strongly disagree

2. I have a poor memory for where I left things.

    strongly agree 1 2 3 4 5 6 7 strongly disagree

3. I am very good at judging distances.

    strongly agree 1 2 3 4 5 6 7 strongly disagree

4. My "sense of direction" is very good.

    strongly agree 1 2 3 4 5 6 7 strongly disagree

5. I tend to think of my environment in terms of cardinal directions (N, S, E, W).

strongly agree 1 2 3 4 5 6 7 strongly disagree

6. I very easily get lost in a new city.

strongly agree 1 2 3 4 5 6 7 strongly disagree

7. I enjoy reading maps.

strongly agree 1 2 3 4 5 6 7 strongly disagree

8. I have trouble understanding directions.
strongly agree 1 2 3 4 5 6 7 strongly disagree

9. I am very good at reading maps.

strongly agree 1 2 3 4 5 6 7 strongly disagree

10. I don't remember routes very well while riding as a passenger in a car.

strongly agree 1 2 3 4 5 6 7 strongly disagree

11. I don't enjoy giving directions.

strongly agree 1 2 3 4 5 6 7 strongly disagree

12. It's not important to me to know where I am.

strongly agree 1 2 3 4 5 6 7 strongly disagree

13. I usually let someone else do the navigational planning for long trips.

strongly agree 1 2 3 4 5 6 7 strongly disagree

14. I can usually remember a new route after I have traveled it only once.

strongly agree 1 2 3 4 5 6 7 strongly disagree

15. I don't have a very good "mental map" of my environment.

strongly agree 1 2 3 4 5 6 7 strongly disagree

APPENDIX B

EXPERIMENT QUESTIONNAIRE

Familiarity with UO Knight Library

1. How many times have you visited the "Knight Library" at the University of Oregon?

   5 or less More than 5 times

2. Do you know where the “Video Section” at the Knight Library is?

   Yes No

3. Do you remember where the “Library Administration” section is?

   Yes No

4. Do you know where the “Document Center” at the Knight Library is?

   Yes No

Personal Information

Please complete the following questionnaire about yourself.

1. Age _______________

2. Male or Female (circle one)

3. Occupation

____

a. If a student, what major ____

4. Check any of the occupation below in which you have worked and indicate how long you worked.

Occupation	Years
___ Census taker	________
___ Delivery or Route-based occupation	________
___ Forest Ranger	________
___ Geoscientist	________
___ Military Personnel	
Branch/MOS ___________________________	________
___ Pilot	________
___ Public Safety Personnel	________

5. Do you participate in any of the following recreational activities? Check all that apply and indicate how often.

Activities	Days per Year
___ Boating	________
___ Geo-caching	________
___ Hiking	________
___ Orienteering	________
___ Piloting	________

Experiment experience

Please answer the following questions regarding the experiment experience. Circle the answer that best identifies your opinion.

1. Did you have trouble following directions?

1 2 3 4 5

No Yes

2. Do you feel that you have spent enough time to look around before following one instruction?

1 2 3 4 5

Not enough Plenty of time

. How difficult were these tests to find errors?

1 2 3 4 5

Difficult Easy

4. In general, were you able to find errors correctly in reasonable amount of time?

1 2 3 4 5

Not able Able

5. For people who did navigation in the computer program, what would you suggest for improvement?

Computer Familiarity

Please answer the following questions regarding your computer familiarity. Circle the answer that best identifies your situation.

1. Are you comfortable with using a computer?

1	2	3	4	5
Very comfortable				Not at all comfortable

2. How often do you use computers at home?

1	2	3	4	5
Almost every day	a few times a week	few times a month	less than once a month	Never

3. How often do you use computers at school (or at work)?

1	2	3	4	5
Almost every day	a few times a week	few times a month	less than once a month	Never

4. How often do you play computer games?

1	2	3	4	5
Almost every day	a few times a week	few times a month	less than once a month	Never

5. How often do you use Internet?

1	2	3	4	5
Almost every day	a few times a week	few times a month	less than once a month	Never

APPENDIX C

SUBJECTS' INSTRUCTIONS FOR THE EXPERIMENT

Physical Navigation Group

This is an experiment on recognizing bad navigation directions. Sometimes we get bad directions from others while following a route.

The experiment will be conducted by using walking routes inside the Knight Library at the University of Oregon campus. For this experiment you will have to complete three different route following tasks. You will be given three separate direction sets (written on papers) to follow and complete the tasks. Each direction set consists of - (1) a goal location to reach (always correct and does exist), and (2) a set of walking directions to follow (possibly incorrect). You will walk following the directions and your task will be to recognize errors in the directions.

The directions will only contain the following two types of direction errors:

a) Missing instruction - a necessary direction is omitted.

b) Wrong instruction - a direction is described incorrectly.

Performance and Payment:

Your performance on the task will be scored as follows:

a) Two points for recognizing every incorrect direction before following the next direction.

b) One point for recognizing every incorrect direction after following next direction.

If you take long time to find errors, you will be stopped by the researcher and will be asked to start the next task.

You will be rewarded with one dollar for each point you earn. You will get $5 for general participation, $4 for answering post experiment questionnaire and up to $6 based on your score for this experiment. Total you will be able to get $15(max) if you score full points and $9(min) if you get no point.

As soon as you find an incorrect direction and the correct suggestion, please let the researcher know so that he can take note.

<u>Virtual Navigation Group</u>

<u>Training:</u>

We made a program to do our experiment. Before we begin the experiment, please be familiar with the program to navigate inside the UO Knight Library.

Keyboard controls:

Up – Move Forward

Down – Turn Around

Left – Turn left

Right – Turn Right

This is a 2D model of the Knight Library at UO. To notice what is in your left or right, you might want to hit left or right button before you move forward (Up button). To turn around, please use "Down" button.

Please follow the directions below to get used to with this program. You will start from the "Daily Grind" section of the knight Library ground floor.

1. Walk straight until you see a library sign.
2. Turn right
3. Walk straight until you see the "Ground Floor" map.
4. Now please try to come back to the place where you started.

Trial:

This is an experiment on recognizing bad navigation directions. Sometimes we get bad directions from others while following a route.

The experiment will be conducted by using walking routes inside the virtual Knight Library at the University of Oregon campus. For this experiment you will have to complete three different route following tasks. You will be given three separate direction sets (written on papers) to follow and complete the tasks. Each direction set consists of - (1) a goal location to reach (always correct and does exist), and (2) a set of walking directions to follow (possibly incorrect). You will walk following the directions and your task will be to recognize errors in the directions.

The directions will only contain the following two types of direction errors:

a) Missing instruction - a necessary direction is omitted.

b) Wrong instruction - a direction is described incorrectly.

Performance and Payment:

Your performance on the task will be scored as follows:

a) Two points for recognizing every incorrect direction before following the next direction.

b) One point for recognizing every incorrect direction after following next direction.

If you take long time to find errors, you will be stopped by the researcher and will be asked to start the next task.

You will be rewarded with one dollar for each point you earn. You will get $5 for general participation, $4 for answering post experiment questionnaire and up to $6 based on your score for this experiment. Total you will be able to get $15(max) if you score full points and $9(min) if you get no point.

As soon as you find an incorrect direction and the correct suggestion, please let the researcher know so that he can take note.

APPENDIX D

CONSENT TO PARTICIPATE IN A ROUTE-FOLLOWING PROJECT

(Physical Navigation Group)

You have been invited to participate in a research project conducted by Raihan Masud from the University of Oregon. The goal of this project is to study how people follow written directions.

By signing this form, you acknowledge that you have read and understand the following.

_____ I will be asked to follow walking directions for trips within Knight Library.

_____ The entire time needed for this experiment will take approximately 30 minutes.

_____ I will be using directions handed to me by a researcher. The researcher will accompany me on the routes.

____ After the experiment, the researcher will ask me to fill-out a questionnaire that focuses on travel and walking directions.

_____ I will be paid for my participation as follows: $5 for general participation, $4 for filling out the questionnaire, and $6 if I can answer specific questions about each route.

_____ All the information collected about my direction following is confidential.

_____ I may withdraw from this experiment at any time without penalty or bad feelings being expressed toward me.

_____ I may choose not to answer any question that I do not want to answer, and still participate in the study.

____ Only researchers involved in this project will have access to my information. This information will be kept in a secure database within the computer science department at the University of Oregon. Only code numbers will be kept with this information.

_____ If I have any questions about the project, I can call Dr. Stephen Fickas (541) 346-3964 from the University of Oregon.

_____ If my questions are not answered to my satisfaction by project staff or if I have concerns about this project and my rights as a research participant, I can call the Office of Human Subjects Compliance at (541) 346-2510.

_____ I was given a copy of this form. The researcher met with me and clearly described its consent.

_______________________________________ ______________

Signature of Participant Date

(Virtual Navigation Group)

You have been invited to participate in a research project conducted by Raihan Masud from the University of Oregon. The goal of this project is to study how people follow written directions. By signing this form, you acknowledge that you have read and understand the following.

_____ I will be asked to use a computer program that simulates walking in Knight Library. I will be asked to use this program to follow walking directions for trips within Knight Library.

_____ The entire time needed for this experiment will be approximately 30 minutes, including training on use of the computer program.

_____ I will be using directions handed to me by a researcher. The researcher will sit beside me as I use the computer program to follow the directions.

____ After the experiment, the researcher will ask me to fill-out a questionnaire that focuses on travel and walking directions.

_____ I will be paid for my participation as follows: $7 for general participation, $5 for filling out the questionnaire, and $3 if I can answer specific questions about each route. Researcher will email me whenever my payment is ready and there after I will be able to pick up the payment at Computer Science Department's front desk at Deschutes Hall at the University of Oregon. It will take a week or two but no later than a month.

_____ All the information collected about my direction following is confidential. It will be kept on a secure server, and no information that links me personally to the data will be kept beyond 2 months.

_____ I may withdraw from this experiment at any time without penalty or bad feelings being expressed toward me.

_____ I may choose not to answer any question that I do not want to answer, and still participate in the study.

_____ Only researchers involved in this project will have access to my information. This information will be kept in a secure database within the computer science department at the University of Oregon. Only code numbers will be kept with this information.

_____ If I have any questions about the project, I can call Dr. Stephen Fickas (541) 346-3964 from the University of Oregon.

_____ If my questions are not answered to my satisfaction by project staff or if I have concerns about this project and my rights as a research participant, I can call the Office of Human Subjects Compliance at (541) 346-2510.

_____ I was given a copy of this form. The researcher met with me and clearly described its consent.

______________________________________ ______________

Signature of Participant Date

APPENDIX E

TEST ON THE DISTRIBUTION OF DATA

A test on the distribution of data is performed to identify the appropriate data analysis method for hypothesis testing. As listed in Table E1, all the scores by Tasks are not normally distributed as the p-value is much less than the level of significance. So, we can reject the null hypothesis that the data came from normal distribution.

	Shapiro-Wilk			**Kolmogorov-Smirnov**		
	Statistic	Df	Sig.	Statistic	Df	Sig.
Task1 of Physical Group	W=0.763	14	0.002	D = 0.273	14	0.006
Task 1 Virtual Group	W = 0.750	14	0.001	D = 0.311	14	0.001
Task2 of Physical Group	W=0.627	14	0.000	D=0.428	14	0.000
Task 2 Virtual Group	W = 0.545	14	0.000	D=0.466	14	0.000
Task3 of Physical Group	W = 0.750	14	0.001	D = 0.311	14	0.001
Task 3 Virtual Group	W=0.639	14	0.000	D=0.369	14	0.000

Table E1: Normality test of the scores by Tasks

APPENDIX F
CHI-SQUARE TEST PERFORMED IN SPSS SOFTWARE

Data was entered into SPSS 17.0. Categorical data analysis (Pearson Chi-Square) was performed to report any significance difference in error detection performance between a physical environment (PE) and a virtual environment (VE) group of participants for any task. SPSS Syntax is shown in Table F1.

```
CROSSTABS

 /TABLES=Group BY Task1 Task2 Task3
/FORMAT=AVALUE TABLES   /STATISTICS=CHISQ
/CELLS=COUNT EXPECTED ROW COLUMN TOTAL
/COUNT ROUND CELL.
```

Table F1: SPSS Syntax for Chi-Square Test

In Table F2, preprocessed data for the test is listed. Group 0 represents the physical navigation group, and Group 1 represents virtual navigation group. For gender, 1 represents male and 0 represents female. Task1, Task2 and Task3 are the three different route following tasks. For each of these tasks 0, 1 and 2 are the possible scores.

ID	Group	Gender	Age	Task1	Task2	Task3
1	0	1	22	0	2	1
2	0	0	20	2	2	2
3	0	1	22	1	2	0
4	0	1	22	2	2	0
5	0	0	19	2	1	1
6	0	0	21	0	2	0
7	0	0	19	2	2	2
8	0	0	19	1	2	0
9	0	1	18	1	1	0
10	0	0	19	0	1	0
11	0	0	37	2	2	1
12	0	1	29	0	0	2
13	0	1	22	0	2	0
14	0	1	23	2	2	2
15	1	1	23	2	2	0
16	1	1	17	0	1	1
17	1	0	20	0	0	0
18	1	0	20	2	2	0
19	1	0	22	0	2	0
20	1	1	19	2	2	1
21	1	0	18	2	2	0
22	1	0	26	1	2	0
23	1	0	20	2	2	1
24	1	1	20	2	2	1
25	1	0	21	1	2	1
26	1	1	23	2	2	1
27	1	1	24	0	1	1
28	1	1	27	1	2	1

Table F2: Processed data for SPSS Chi-Square Test

Table F3 shows the tabular representation of the observed and expected frequency counts for each of the possible scores for Task1 against the groups. Table F4 lists the Chi-Square test results for Task1.

			Task1			
			.00	**1.00**	**2.00**	**Total**
Group	**0**	Count	5	3	6	14
		Expected Count	4.5	3.0	6.5	14.0
		% within Group	35.7%	21.4%	42.9%	100.0%
		% within Task1	55.6%	50.0%	46.2%	50.0%
		% of Total	17.9%	10.7%	21.4%	50.0%
	1	Count	4	3	7	14
		Expected Count	4.5	3.0	6.5	14.0
		% within Group	28.6%	21.4%	50.0%	100.0%
		% within Task1	44.4%	50.0%	53.8%	50.0%
		% of Total	14.3%	10.7%	25.0%	50.0%

Table F3: Cross tabular (Crosstab) representation of Group * Task1

	Value	**Df**	**Asymp. Sig. (2-sided)**
Pearson Chi-Square	.188	2	.910
Likelihood Ratio	.188	2	.910
N of Valid Cases	28		

Table F4: Chi-Square Tests for Task1

Table F5 shows the tabular representation of the observed and expected frequency counts for each of the possible scores for Task2 against the groups. Table F6 lists the Chi-Square test results for Task2.

			Task2			
			.00	**1.00**	**2.00**	**Total**
Group	**0**	Count	1	3	10	14
		Expected Count	1.0	2.5	10.5	14.0
		% within Group	7.1%	21.4%	71.4%	100.0%
		% within Task1	50.0%	60.0%	47.6%	50.0%
		% of Total	3.6%	10.7%	35.7%	50.0%
	1	Count	1	2	11	14
		Expected Count	1.0	2.5	10.5	14.0
		% within Group	7.1%	14.3%	78.6%	100.0%
		% within Task1	50.0%	40.0%	52.4%	50.0%
		% of Total	3.6%	7.1%	39.3%	50.0%

Table F5: Cross tabular (Crosstab) representation of Group * Task2

	Value	**Df**	**Asymp. Sig. (2-sided)**
Pearson Chi-Square	.248	2	.884
Likelihood Ratio	.249	2	.883
N of Valid Cases	28		

Table F6: Chi-Square Tests for Task2

Table F7 shows the tabular representation of the observed and expected frequency counts for each of the possible scores for Task3 against the groups. Table F8 lists the Chi-Square test results for Task3.

			Task3			
			.00	**1.00**	**2.00**	**Total**
Group	**0**	Count	7	3	4	14
		Expected Count	6.5	5.5	2.0	14.0
		% within Group	50.0%	21.4%	28.6%	100.0%
		% within Task3	53.8%	27.3%	100.0%	50.0%
		% of Total	25.0%	10.7%	14.3%	50.0%
	1	Count	6	8	0	14
		Expected Count	6.5	5.5	2.0	14.0
		% within Group	42.9%	57.1%	.0%	100.0%
		% within Task3	46.2%	72.7%	.0%	50.0%
		% of Total	21.4%	28.6%	.0%	50.0%

Table F7: Cross tabular (Crosstab) representation of Group * Task3

	Value	**Df**	**Asymp. Sig. (2-sided)**
Pearson Chi-Square	6.350	2	.042
Likelihood Ratio	7.980	2	.018
N of Valid Cases	28		

Table F8: Chi-Square Test for Task3

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