Technology Project: The Cognitive Ergonomics of Interactive Decision-making in Personal- and Action-Space within 3D Virtual Reality Environments

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Index Terms: Immersive analytics and visualization—Perception and cognition—Touch, tangible and gesture interfaces

1 Motivation

Virtual reality environments (VEs) have immense potential to be a platform for visualizing and analyzing information for complex and collaborative decision making due to its interactive and immersive nature. VEs invite their users to become active participants in their comprehension of information. The external visualizations in VEs have the potential to augment cognition and to allow effortful cognitive processes to be off-loaded onto less effortful visual system processes. The results of previous controlled studies of the effects of interactivity in visual-spatial tasks are mixed. A study [5] on spatial reasoning with external visualizations concluded that interactive visualization does not necessarily enhance task performance, whereas seeing the most task-relevant information does, and this is true regardless of whether the task-relevant information is obtained actively or passively. Thus, the VE design can be instrumental in accurately conveying relevant information to the user which is important for decision-making. If we purport interactive VEs to effectively extend analytic workspaces, we must guarantee that this effectivity is invariant with respect to interactivity.

According to our hypothesis, the way of information presentation affects the decision-making process within interactive VEs. The space around the user can be segmented into personal space (the zone surrounding the user within arm's reach; typically, within 2 meters) and action space (the circular region just beyond personal space; typically, within 30 meters). Prior work [3] has demonstrated that people attend to these spaces differently.

In this project, we aim to study the effect of varying depth of presentation of information on decision-making. The decision-making effectiveness can be measured by VE activity and decision-making performance. According to our hypothesis, an improved decision-making performance and better VE activity can be achieved by the presentation of information at optimal depth.

2 Technical Details

With this project, we want to answer the question: "What is the effect of perceived spatial depth on decision-making within interactive VEs?" Here, we focus on part of that question by looking at decision-making as a function of two kinds of spatial depth ranges: personal space and action space. Essentially, the user will attempt the decision-making task with varying depth of information presentation and the decision-making performance and VE activity will be compared across different VE configurations.

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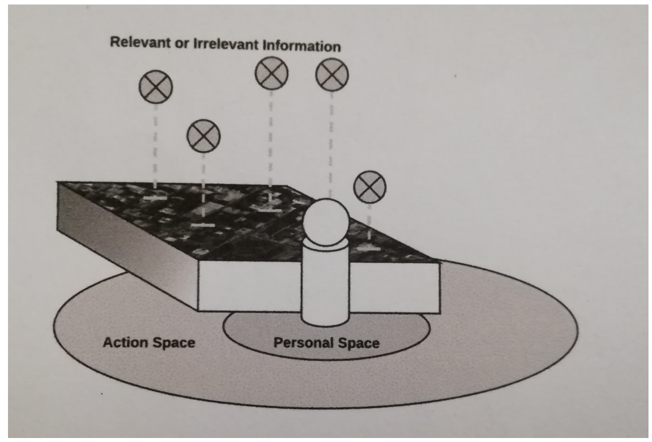

Figure 1: Illustration of the experiment task, distinguishing between decision-making information within action space vs personal space.

2.1 VE Experimental Task

Our experimental task is an expansion of the decision-making task in this prior work [1].

2.1.1 Prior Task Details

In this task, a terrorist has been leaving bombs in crates around a fictional city. Officials believe the terrorist is following a pattern in choosing their targets. The user is expected to determine the most likely location for the next crate to be placed in so that security can be increased within the area. The time limit is 10 minutes.

A map of a fictional city was created using Unity version 5.6.3, VRTK version 3.1. Socio-cultural information was displayed with user controlled overlays. The participants interacted with the app using HTC Vive controllers. The map-overlays were on a shelf located to the side of the map in reach of the participant. Participants activated overlays by grabbing them with controllers and placing them on the circles at the front of the table. The timer was located at the front left of the table. Participants were free to move within the virtual environment and could view the map from both an egocentric and allocentric perspective (by looking directly down on the map).

To assist with this, the user had access to a 3D visualization of this fictional city containing information about the city and the previous attacks. The information consists of relevant information (government building locations and bus routes) and irrelevant information (traffic, income for areas, flood zones, park locations, and religious centers). All information was presented within personal space.

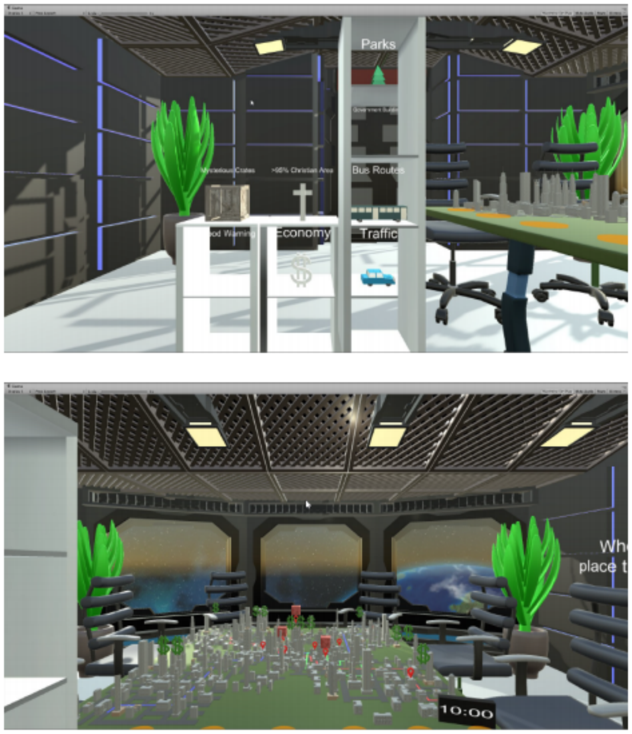

Figure 2: The information presentation in the prior task.

2.1.2 Proposed Modifications

The following modifications are proposed in the prior task to make it suitable for our problem:

- Prior work [6] presents a set of ten low-level analysis tasks that largely capture peoples activities while employing information visualization tools for understanding data. These primitive tasks are to retrieve, filter, derive, find extrema of, sort, determine the range of, characterize the distribution of, detect anomalies within, cluster, and correlate data. The user will be able to perform a subset of these ten primitive analysis tasks to make an informed decision within our interactive VE .

- The relevant and irrelevant information will be presented at variable depth (personal and action space). There are multiple ways to approach this design problem. First, certain number of fixed configurations of information presentation will be available to the user. These fixed configurations will be synthesized by varying the depth of relevant and irrelevant information in the interactive VE. Second, the user will be allowed to arrange/move around the information from a fixed starting point according to their preference and solve the decision-making task. The final configuration of the information presentation with respect to the depth will be recorded.

- The position of map overlays will be modified as the depth is not restricted to personal space anymore. The feature of selecting from the primitive tasks and displaying its results will be added.

- Touch and gesture inferface can be used for interaction instead of controller based input if they are more intuitive and user friendly in our interactive VE.

2.2 VE Experimental Study

In this study, the depth range (personal, action) and information relevance (relevant, irrelevant) are independent factors. This study is a 2x2 within-subjects design. Every participant will be exposed to four VE configurations one after the other:

- relevant and irrelevant information in the personal space

- relevant and irrelevant information in the action space

- relevant information in the personal space and irrelevant information in the action space

- relevant information in the action space and irrelevant information in the personal space

In an experiment on problem solving, some subjects may perform better than others regardless of the condition they are in due to differences in their skills. Within-subjects designs control these individual differences by comparing the scores of a subject in one condition to the scores of the same subject in other conditions. However, if all the subjects attempt the task in the same order of VE configurations the results may be biased. This can be addressed by counterbalancing the order of VE configurations.

2.3 Method of Analysis

The dependent variables indicating the decision-making performance and VE activity will be recorded. Specifically, they are:

- Number of incorrect predictions

- Time to each prediction

- Information usage count: which category of information was used and what primitive tasks were performed on it

- Locomotion displacement from starting location

This study has 2 nominal independent variables and scale dependent variables. Also, it has repeated measures due to the within-subjects design. Thus, for testing the hypothesis, 2 way repeated measures ANOVA test will be used.

2.4 Hypothesis

The null hypothesis is that variation in the depth of presentation of information does not affect decision-making. In this case, the participants are expected to exhibit similar decision-making performance and VE activity i.e. they will have similar number of incorrect predictions, time to each prediction, information usage count and locomotion displacement from starting location in all four configurations.

Our alternative hypothesis is that variation in the depth of presentation of information affects decision-making. In this case, the participants will have significantly better decision-making performance and VE activity in one of the four configurations. They are expected to have a lesser number of incorrect predictions, lesser time for each prediction, and lesser information usage count. It is hard to comment about locomotion displacement from starting location. It depends on whether personal or action space space is the perceived depth for effective decision making.

2.5 Power Analysis

The parameter values used for power analysis for 2 way repeated measures ANOVA test are as shown in the table below:

Effect size	0.1	0.25	0.4
Significance level	0.05	0.05	0.05
Power	0.80	0.80	0.80
Sample Size	273.5429	44.59927	18.04262

The sample size is evaluated for 3 values of effect sizes 0.1, 0.25, and 0.4 represent small, medium, and large effect sizes respectively. For medium effect size we will require at least 45 participants to reject the null hypothesis. The 'pwr' package in R was used for these calculations.

3 ETHICAL IMPACT

With great power comes great responsibility.

3.1 Privacy

Most of the Virtual Reality(VR) technologies have access to user's personal information like patterns of eye movement, motor responses, and reflexes, which together constitute a persons distinct 'kinematic fingerprint. Yet more information about the habits, interests, and tendencies of VR users may be captured as well, which could be stored and deployed in ways that threaten personal privacy [7].

Since this is a data visualization tool, its software will have access to the data visualized by the user as well. This raises major concerns about the privacy of this data. In certain cases, this tool can have access to sensitive data which may be dangerous if shared/sold to other agencies. Data related to national security, health records, financial records are examples of sensitive data.

3.2 Manipulation

This tool is useful to assist people in making complex decisions effectively with the help of visualizations and the low-level data analysis features. According to our hypothesis, the way of information presentation affects the decision making process. Additionally, problematic representations or misrepresentation of information can affect the decision itself. The risk of personal manipulation is even more grave than privacy violation.

Since VEs can be readily modified according to specific aims of influencing beliefs, emotions, and behavior, such manipulative potential could be easily exploited for a variety of purposes, ranging from commercial to political ends [7]. Any misrepresentations can alter users views of actual individuals, people groups, objects and perspectives on real life issues. VR programs could be used to manipulate users in other ways as well in order to influence their offline behaviors [2].

4 SOCIETAL IMPACT

Virtual reality (VR) is a powerful technology with a potential to alter human society. VR has the ability to change perceptions and interactions and hence it can lead to massive psychological consequences. Most of the social risks are associated with the way VR blurs the distinction between the real world and the illusion. The immersive and addictive nature of certain VR technologies are the root causes of most mental health issues. In some cases, the VEs welcome aggressive, sexual, age inappropriate, unacceptable behaviour which is unacceptable in the real world and this may result in concerning offline behaviour [4]. However, this particular project is very different from these kind of VR technologies. In my opinion, there are no negative societal implications.

The application of effective data visualization for improved decision-making in interactive VE can be found in almost every field. Practically, any complex decision-making task with an associated dataset will be benefited with this project. It is self-evident that improved decision-making will benefit the society as a whole. Some important possible applications are as follows:

- In academia research with the advances in science, we are dealing with tons of data. The knowledge of effectiveness of data visualization as a function of perceived depth can help to create better VE designs for analytical task in interactive VEs.

- In the field of health and medicine, a doctor can use a more effective data visualization tool for better insight in complicated cases. It will be helpful for accurate analysis of patient's disease based on his health records.

- In field of teaching and learning, better visualization tools will help the students to grasp the subject better. With the advantage of interactivity, the learning process can become more practical and hence more effective.

5 OPEN QUESTIONS

- This project is designed for a single user task. However, application-wise it will make more sense to study this problem for multi-user case. That way we can actually study the effectiveness for collaborative decision-making scenario. However, multi-user case adds certain complexity to the task since depth is relative to user's position.

- Every decision-making task requires specific type of information and visualizations. Its the task of the VE designer to incorporate these things in the environment. So the question is can we generalize the result of this study to other similar VEs? What is the criteria of deciding which VE is similar and which is not?

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