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Testing the Use of Egocentric Interactive Techniques in Immersive Virtual Environments

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Abstract: Navigation, object selection and manipulation in virtual environments are based on interaction methods or techniques driven by conventional or special devices. There are a number of techniques and devices available for the development of applications involving interaction in immersive worlds, and to choose the most suitable one for a given situation is a difficult task. This paper reports the evaluation of selection and manipulation techniques in an immersive environment based on a chess game. The techniques evaluated in the experiment were the virtual hand, associated to a common mouse or data glove, and the ray-casting, used with a data glove. We propose some hypotheses and discuss experimental results.

Keywords: 3D interaction, virtual reality, immersive worlds, evaluation, selection, manipulation.

1 Introduction

Interaction in Virtual Reality Environments (VRE) is based on the responsive capability to detect and react to each user action, making use of some kind of special (data gloves, H3D glasses) or conventional (mouse, keyboard, screen) device. We use classical Norman's model of human-computer interaction [Norman 88] to help explaining our understanding of interaction in VREs (Figure 1).

Basically, the difference between interaction by means of 2D graphical interfaces and 3D immersive interaction is that, in the second case, we should take into account another component in the schema. While in the general case we consider the message exchange between user and computer, in the special case of VREs, we should consider three components: the computer that receives information (impulses) and reacts to them generating images and other impulses as feedback to the actuator; the actuator, characterized by the input devices; and the user, which receives visual information from the computer (images) and tactile feedback from the actuator. It is important to point out that tactile feedback, as well as the transmission of information from the computer to the actuator is possible only when the actuator corresponds to a haptic device.

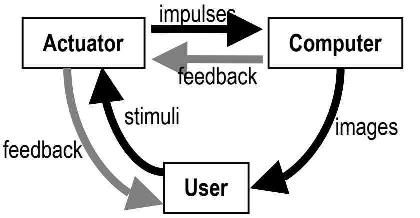

Figure 1: Human-computer interaction for VREs.

Independently of the idiosyncrasies of each VR application context, user actions have typically three main goals: to select virtual objects, to manipulate them, and to navigate in the 3D environment. User actions are accomplished by means of usual interaction techniques available to specify actions, to execute commands and to enter data in the VRE.

Reactions usually include instantaneous modifications in the VRE state, make known through the output devices. State changes are perceived and interpreted by the user jointly with expectatives based in previous experience using the VRE in order to decide a new action, in a continuous and dynamic process. Among the attributes used in output devices to increase user perception, we include colors, textures, size, perspective view, occlusion, shadows, and user movement.

There are several possible interaction techniques we may choose to provide good support for users acting in a VRE. Obviously, some techniques are more appropriate for a specific kind of action than others. However, despite the increasing number of available VR tools and applications, surprisingly very little attention has been given to the evaluation of VR interaction techniques or more generally to usability studies of VREs. The main reason for these limited efforts is probably that empirical user testing with VREs is difficult and time-consuming.

This work aims to analyze some 3D interaction techniques and to discuss which technique is preferred by users, why and in which circumstances. Our overall goal is to help VRE developers to understand how to select more suitable VR interaction techniques for a given situation.

In this paper, we specifically report the evaluation of selection and manipulation techniques in an immersive virtual environment based on a chess game. We describe the process and results of evaluating the *virtual hand* technique, associated to a common mouse or a data glove, and the *ray-casting* technique combined with a data glove.

Next section briefly reviews 3D interaction concepts and existing metaphors and techniques. In Section 3 we describe the testbed application in terms of interaction techniques implemented, devices used and visualization options. Section 4 points out the evaluation criteria we use to guide the experiment, describing the hypotheses formulated, the independent variables and the definition of the performance criteria, while Section 5 describes the experiment in detail. In Section 6 we present the analysis of the data gathered during the experiment and discuss the results. Finally, in the last section, we draw some final considerations.

2 Background

Objects selection and manipulation techniques in 3D spaces can be classified in two categories, according to the interaction metaphor used: the egocentric ones, where the user take part of the virtual world maintaining the dimensional coherence between the user and the objects manipulated; and the exocentric metaphor, where the proportions between the user and the objects are not considered, assuming that the user interacts with the environment outside its reference system [Poupyrev 1998].

Since we are especially interested in exploring interaction in immersive VREs, which presumes that the user is part of the environment, we adopt egocentric metaphors. As mentioned before, the selection and manipulation techniques chosen for the experiment were *virtual hand* and *ray-casting.*

In the *virtual hand* technique, the user's hand is explicitly represented in the virtual environment. User's position and orientation in the VRE are provided to the system by means of specific input devices. To select an object, the user should intercept the object with the hand and inform his intention to the application. This can be provided simply by pressing a button on the input device or performing a specific gesture with the fingers, in the case the user is interacting by means of a data glove [Poupyrev 1996, Bowman 2001].

The *ray-casting* is one of the most used techniques to select and manipulate objects [Poupyrev 1998, Bowman 1997]. This technique consists of the representation of an infinite and semi-transparent ray starting at the user's hand and with its direction guided by the hand orientation. To complete a selection operation, the user should point at an object and inform the application about his selection intention, through the input device.

3 Testbed Application

In order to support the experiments to evaluate selection and manipulation of 3D objects in VREs, we implemented a testbed application: a virtual chess game. This section presents the design of our application, the interaction and visualization options we provide and the apparatus used in the implementation.

3.1 Application design

Our virtual chess game is inspired on a chess game, when the player tasks involve the selection and motion of pieces over the chessboard, with no care with the player cognitive capacity or the game rules.

The virtual environment is composed by a chessboard with 64 squares (cells) containing, in general, 32 chessmen. Each player has 16 chessmen: a king, a queen, 2 bishops, 2 knights, 2 rooks and 8 pawns. The pieces are identified by the colors beige and gray. During the tests, when it is convenient for the proposed task, some pieces are removed.

The chessboard is displayed in two different ways. In the **perspective view**, we try to simulate approximately the same view angle of a player when in a real chess game, as shown in Figure 2. The **top**

view gives us a top view of the chessboard, simulating, in some way, a 2D interface (Figure 3).

3.2 Interaction and Visualization

In a real chess game, the movement of the pieces over the game board is performed with the hand. This can induce us to consider the virtual hand as the most intuitive technique for the egocentric metaphor to manipulate the chessmen in our testbed application. For this reason, we choose to implement and test the virtual hand interaction technique (Figure 2.a).

However, compared to others, this technique was not considered a good choice in experiments reported by Poupyrev (1997). For this reason, we decided to implement and test also the *ray-casting* technique (Figure 2.b). As a result, we can compare the performance of the two techniques for manipulating objects located near the user. The main difference between this work and Poupyrev's is that our virtual chess involves much more interactive objects than in the trials performed by Poupyrev.

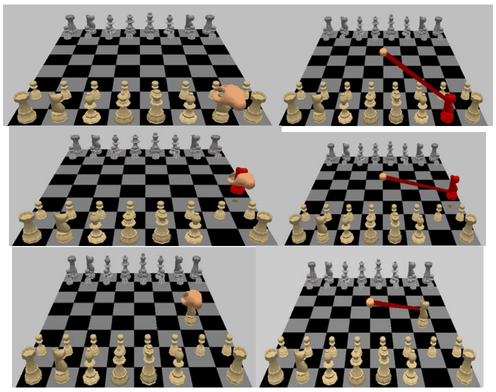
(a) (b)

Figure 2: Virtual chess perspective view. In the left column, the interaction technique is the virtual hand (a) and in the right column, the ray-casting (b). From top to bottom, the pictures show a complete interaction task performed with visual feedback. The user select, move and leave the chessman in the target square.

Concerning the visual feedback when selecting and manipulating the chessmen, we have designed two different situations during the tasks: with and without visual feedback. During the tasks performed with visual feedback, when a piece is selected, its color changes (from gray or beige to red) and is automatically suspended, projecting shadow over the chessboard. The objective is to allow the easy identification of the selected chessman. Figure 2 and Figure 3.a illustrate game situations with visual feedback.

As our purposes involve the analysis of user performance during the interaction tasks in VRE, the immersion sense is an important issue to be considered. For this reason, we also implemented stereoscopic view when using the perspective view mode. In the top view mode, the user has the impression he is playing a computer chess game (usually provided with 2D interface). In this case, the notion of distance from the player to the pieces is less important and the use of stereoscopic vision not relevant.

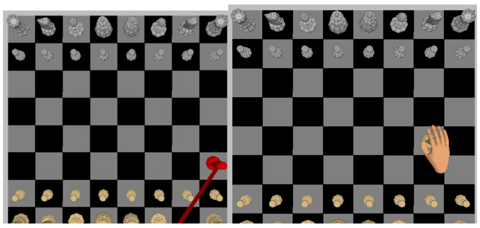
(a) (b)

Figure 3: Interaction using (a) the ray-casting technique and (b) the virtual hand, both with the top view.

3.3 Apparatus

The features of the input and output devices used in an application affect the user performance during the execution of a task [Mackenzie 1995, Poupyrev 1997]. Attributes like degrees of freedom, resolution, field of vision, maximum supported depth, etc. should be considered when comparing users' performance.

In the virtual chess, we use four different devices, as described below: mouse, data glove, motion captors and 3D stereoscopic glasses.

Nowadays, the mouse is a conventional device for interaction with 2D graphics applications. People consider that interaction attained by the mouse is really "intuitive" and "natural" for users familiarized with computers and windows-based operating systems. A common mouse was used in the selection and manipulation tasks of the chessmen, guiding a virtual hand.

We have also used a data glove model 5DT from Fifth Dimension Technologies (Figure 4). This data glove has a rotation and orientation sensor and five flexion sensors for the fingers. This device allows the recognition of user gesture, from a combination of finger flexions. In virtual chess, the data glove was used to perform tasks involving objects selection and manipulation, either combined with the *virtual hand* and *ray-casting* technique. Closing the hand is recognized as the action of selecting an object. After a well-succeeded selection, the piece is moved in the VRE while the real hand (still closed) moves, until the releasing in a determined position of the chessboard, which was implemented from the opening hand gesture recognition.

As this equipment does not support translation, we used the data glove combined with a magnetic motion captor Flocks of Birds (Ascension Technology Co.), with one sensor attached to the data glove on the user wrist – see Figure 4.

For the chessboard visualization in perspective view mode, we used stereoscopic glasses from H3D Glasses.

The application was developed in C++ using the OpenGL graphics API, and the experiments were conducted in a PC computer with Pentium 4 processor, RAM memory of 256 MB, a GeForce2 graphics board from nVidia Corporation and Microsoft Windows 2000 operating system.

Figure 4: 5DT Data Glove and the motion captor Flocks of Birds (Ascension Technology). The captor is attached to the data glove, to the wrist, while the emitter is on the table, in the upper-right corner.

4 Evaluating Interaction

Taking into account the human-computer interface evaluation methods used in the area of HCI [Dix 1997] and in some known experiences involving the evaluation of virtual environments [Bowman 1999, Poupyrev 1998], we defined the methodology to be used for the evaluation of the implemented techniques. We defined five hypotheses, determined a set of independent variables (that should be changed to test the hypotheses), and the dependent ones (that indicate the users performance criteria).

4.1 Hypotheses

The conceived hypotheses involve usability issues as well as user performance, measured by means of objective metrics.

1. The user prefers to work with a top view of the chessboard and will have difficulties to work with a perspective view.

This hypothesis tests, in fact, if the user awareness regarding 2D interfaces will drive the option to this kind of interfaces in defeat of 3D interfaces. This hypothesis supposes also that the subjects will have troubles to select and manipulate the chessmen with the perspective view.

2. The visual feedback would positively affect subjects' performance both in selection and manipulation tasks.

Poupyrev (1998) affirmed that visual feedback does not induce user performance. The hypothesis to be tested is that with a large number of objects, as in a chess game, the visual feedback will help to distinguish and move the pieces.

3. The virtual hand will be the favorite interaction technique when using a data glove.

Despite ray-casting is a good technique to "grab objects", it presents a poor performance to move pieces in-depth. In operations like changing the distance between the user and the objects [Bowman 1997, Poupyrev 1998], ray-casting is not satisfactory. In the case of chess game, the hypothesis to be tested is that the virtual hand guided by the data glove presents a better performance when compared to the ray-casting technique. It will also be considered the best option, because it is analogous to the interaction in real world.

4. The mouse will be the preferred input device.

This hypothesis evaluates the association between the user experience with the mouse to select and manipulate objects in VRE, and the preference for the mouse mentioned by the users in the questionnaires. We suppose that users familiarized with computers will prefer to select and manipulate the pieces on the chessboard using the mouse.

5. The user will have a better performance when using the ray-casting technique with the top view.

The ray-casting technique is considered a 2D technique and the hypothesis is that the user has always a better performance when using this technique with the top view.

4.2 Independent variables

Independent variables are the experiment variables that are manipulated to generate different conditions to compare. In general, good examples of independent variables in interfaces are interface style and help level [Dix 1997]. In VREs, an example is the size of the object that should be selected and/or manipulated. In the virtual chess, we established the following variables to test the hypotheses.

Chessboard view. This variable allows the direct test of the first hypothesis. It is also considered in the composition of the situation used to verify the fifth hypothesis. The two possible orientations are top view and perspective view.

Visual feedback. Used to configure the second hypothesis, this variable indicates the use of the visual feedback in piece selection: the piece automatically becomes highlighted, keeping red and producing shadow on the chessboard, while floating. Without visual feedback, the selected piece is not highlighted; the only way to perceive that it is really selected is the fact the piece is suspended.

Device in use. The hypotheses 3, 4 and 5 are directly dependent of the device in use. The available input devices for this testbed are the data glove and the mouse. When using the mouse, the cursor is represented by a virtual hand, configuring the test situation of hypothesis 4; when using the data glove, the cursor position depends on the technique in use (virtual hand or ray-casting).

Interaction technique associated to the data glove. Two techniques were implemented with the data glove: virtual hand and ray-casting. The third hypothesis is based on the configuration established with this variable while the fifth hypothesis combines the variable "chessboard view" with ray-casting.

4.3 Dependent variables

Dependent variables are the measures taken as the performance indicative or level of acceptance of the technique by the users. These measures can be objective, as the time taken to select and manipulate a piece in the chessboard (automatically calculated by the application), or subjective, collected from post-test questionnaires answered by the subjects.

The dependent variables used in our experiment were: interaction technique efficiency, measured by the time to perform each task; usability of the interaction technique, related to the effortless use of the technique; comfort/discomfort of the device in use (data glove or mouse), measured in relation to the arm and hand weight, dizziness and sickness; and user personal opinion about the technique and the device tested.

5 The Experiment

The experiment performed corresponds to the execution of pre-determined movements with some specific chessmen on the chessboard. During the experiment, we have calculated the movement extent and the number of errors from the trial beginning until the correct achievement of each task. Post-tests questionnaires were applied to collect the subjective measures.

5.1 Subjects and Tasks

Twenty-nine subjects volunteered for the tasks: 15 men and 14 women. Four people were professors and the other 25, Computer Science students. The subjects were 20 to 37 years old. Only one subject was left-handed, while the others were right-handed. Twenty-seven people stated do not be familiar with VR equipments, like stereo glasses, data gloves or motion captors. A previous knowledge on playing chess was not required. In the cases where the subjects did not know how to play chess at all, we simply explained during the training phase how to recognize a rook, a knight and a bishop.

The motion tasks applied to pieces were divided in two different groups: side motion (moving a piece in a horizontal way) and in-depth motion, both in relation to the chessboard. Each task involved the selection of a specific piece and its translation to another pre-defined position. Each subject was invited to accomplish a set of 24 tasks: 12 in-depth motion tasks and 12 side motion tasks. From these 24 tasks, 8 were performed with the mouse and 16 with the data glove. In the tasks performed with the data glove, we balanced the two interaction techniques: virtual hand and ray-casting. In 12 tasks, the chess game provided visual feedback, while in other 12, it did not. Twelve tasks were performed with a perspective view and 12 with a top view of the chessboard.

5.2 Methodology

In some preliminary tests, we observed that the identification of some pieces were not easy for the user when playing with the top view. To avoid this drawback, the motion tasks were performed only with rooks, knights and bishops because these are easily identified by the players.

The motion of pieces outside the chessboard is not allowed, as well as the selection of two pieces at the same time.

Before starting the tasks, the subjects had from 5 to 10 minutes of training time. During this phase they could select and manipulate pieces by their own, using the two interaction techniques considered (virtual hand and ray-casting). The instructor explained to each user the tasks to be accomplished, the importance of the evaluation and what kind of things it should be noticed during the trials: selection and manipulation with and without visual feedback; ray-casting and virtual hand techniques; the two visualization modes (top and perspective views); and also the device used (mouse or data glove). The tasks began only after the user showed to be able to clearly identify the bishop, the rook and the knight.

5.3 Procedure

The tasks order were sorted out by the computer and showed to the user through the exhibition of an instruction message on the screen (Figure 5). The instruction message indicated the device to be used (mouse or data glove), which piece should be selected as well as which movement should be performed. The message disappeared with a mouse click or with a hand closing movement (when using the data glove). From the moment the message disappeared, the application started to count the time to complete the selection sub-task. This partial time was recorded when the subject succeeded in the selection of the piece indicated by the instruction message. The selection sub-task ending signalized the beginning of the manipulation sub-task, resetting the time counting. After moving the piece to the correct position, the subject should release it, which stopped the manipulation time computation.


Mouse
put the white rook in
front of the white knight

Figure 5: Instruction message for the task to be performed by the subject.

5.4 Logging

A log file is saved to record all the computed times. It is organized by subject and contains: subject name, piece selection time, manipulation time, number of clicks on escape areas (in the mouse case, when trying to select a piece), pieces wrongly selected (with both devices) and the number of wrong manipulations performed (leaving a piece in a position other than the one indicated in the message).

6 Results and Discussion

As mentioned before, the different conditions for testing the hypotheses were obtained by configuring the independent variables: chessboard orientation, visual feedback, input device and interactive technique used in association with the data glove. Selection and manipulation tasks were planned according to two categories of movements, side movement and in-depth movement. From the log files, selection mean times, manipulation mean times and errors in each case were computed and the time data tabulated (tables with these data are available at the project web address: http://www.inf.ufrgs.br/cg/vr-interaction). Although the cases with large standard deviation occurred due to few users, we decided do not exclude them from the samples.

To verify the five hypotheses, selection and manipulation times recorded in the log files were used as input for ANOVA (Analysis of Variance) test. The results are discussed below, including data from the subjective analysis performed with the users after the experiments.

Regarding the first hypothesis (**subjects prefer to work with a top view of the chessboard**), we observed that although 76% of the users expressed their preference for a chessboard displayed in perspective view, there is no significant difference between these two conditions for a selection involving side movement ("Selection with side movements", Table 1). However, for selection involving in-depth movement, the mean times with the chessboard in top view were significantly smaller (F=39.790; p<0.0001) than those with the perspective view chessboard (see also Table 1). With respect to manipulation, results are different: users showed to have a better performance with side movements using the perspective view (F=8.494; p<0.003), while there is no significant difference for in-depth movement (Table 1).

	Chessboard top view	Chessboard perspective view
Selection with side movements	6.02 ± 5.22	7.01±6.84
Selection with in-depth movements	6.29±4.99	12.22±11.33
Manipulation with side movements	4.66± 4.94	3.47±2.20
Manipulation with in-depth movements	5.71 ±4.55	5.37 ±3.28

Table 1: Performance (in seconds) for selecting and manipulation tasks completion.

Taking into account the number of times the user tried to select a piece without succeeding (moving the hand or clicking the mouse without "touching" a piece), we observe that users experienced difficulties in selecting them with the chessboard in perspective view, while in the manipulation phase no matter the orientation of the chessboard, in-depth movements lead to more unsuccessful trials than side movements.

The second hypothesis was that **visual feedback would positively affect subjects' performance both in selection and manipulation**. Despite the fact that the majority of users mentioned the benefits of visual feedback for improving performance, analysis of time data from the experiments indicate that there are no significant statistical differences in the time measures taken during tasks with and without feedback. It should be noticed that times for this analysis were computed considering only this independent variable, i.e., disregarding different chessboard orientations or different devices or interaction techniques.

The analysis of time results for the third hypothesis (**virtual hand is the favorite technique for use with the data glove**) confirmed for in-depth movement both in selection and manipulation. According to Poupyrev (1998), the ray-casting technique has poor performance for operations that involve changes in the distance between the user and the object. In side movement, however, users' performance is similar for virtual hand and ray casting. Our results agree with Poupyrev's. Figure 6 shows mean times computed for these tasks. In our experiments, selection with the virtual hand is better than with ray-casting both for in-depth (F=17.774; p<0.0001) and side movements (F=7.195; p<0.007). Regarding manipulation, only in the tasks with in-depth movements, users had a better performance with virtual hand than with ray-casting (F=7.207; p<0.007). This preference is also evident in the subjective analysis through users' answers to the post-experiment questionnaire: more than 80% of the users classified the virtual hand as efficient or very efficient.

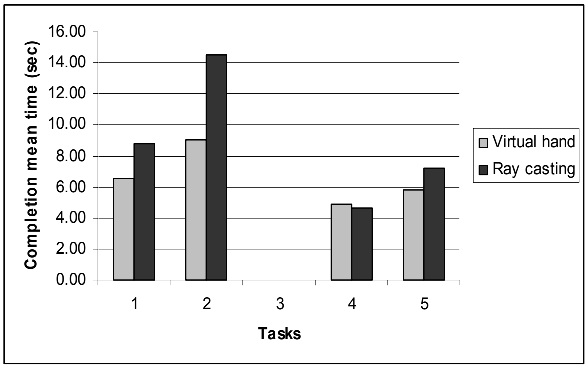

Figure 6: Task completion mean times for selection (1= side movements and 2=in-depth movements) and manipulation tasks (4=side movements and 5=in-depth movements) performed with virtual hand and ray casting techniques.

As was expected, the fourth hypothesis (**mouse is the preferred device**) was confirmed both in the subjective evaluation and in the performance results. The selection completion times (Figure 7) using the mouse were significantly smaller than those recorded with the data glove both for in-depth (F=106.622; p<0.00001) and side movements (F=29.051; p<0.00001). Similar results were obtained for manipulation completion times (Figure 7) for in-depth (F=49.601; p<0.00001) and side movements (F=16,378; p<0.00001).

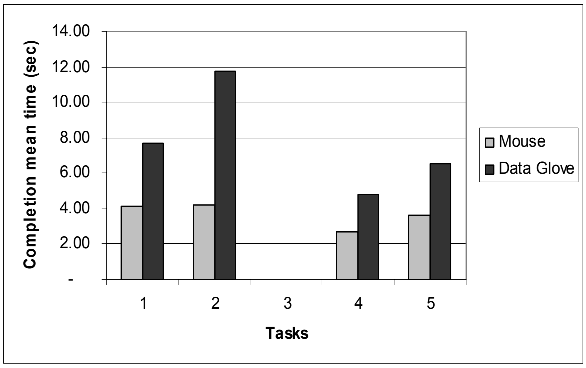

Figure 7: Task completion times for selection (1 and 2) and manipulation (4 and 5) with mouse and data glove.

Finally, the fifth hypothesis (**the user present a better performance when using the ray-casting technique with the top view of the chessboard**) was confirmed in all selection tasks, being the mean times with the top view significantly smaller than those with the perspective view of the chessboard (F=31.352, p<0.00001, for in-depth movements; F=7.718, p<0.006, for side movements). However, when we observe the results from manipulation tasks, only the side movements show significant differences favoring the perspective view chessboard (F=4.754; p<0.03), i.e., there are no differences between the two conditions when tasks involve in-depth movements. Figure 8 shows mean time values from the data analyzed for this hypothesis. It should be noticed that these results do not disagree with those for the third hypothesis, because in the top view chessboard in-depth movements are obtained with vertical movements of the virtual cursor, and not really with movements along a *z* axis.

7 Final Comments

Virtual chess game requests high-precision user movements because there are several pieces on the chessboard. Compared to some previous works concerning remote objects selection and manipulation [Bowman 1997] and manipulation involving at most nine objects in VREs [Bowman 1999], our virtual chess game faces more complexity because it is composed by 32 pieces, although some were removed when it is convenient for determined selection and manipulation tasks.

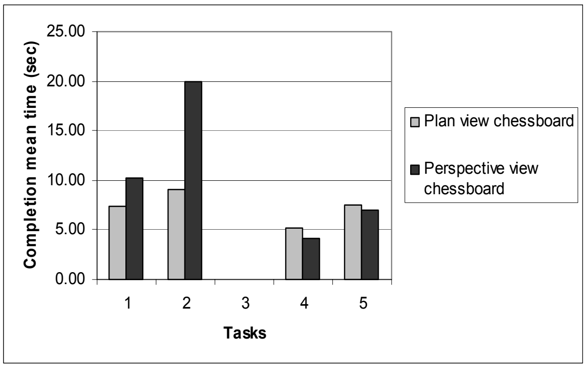

Figure 8: Task completion times for selection (1 and 2) and manipulation (4 and 5) performed with ray-casting in top view and perspective view chessboard.

The evaluation process was performed with Computer Science students and lecturers who volunteered but had no previous experience in using VR devices. In fact, they were specially troubled by specific device characteristics and a lot of time was needed to cope with this unfamiliarity. However, results discussed in Section 6 express only time for successful tasks completion. More statistical analyses are needed in order to take into account the number and the kind of errors recorded, as well as the specific occasion during the tasks they occurred.

In a further work, we intend to compare data from post-experiments questionnaires with performance results reported here in order to understand the reasons of some users having significant different performance in relation to others. We are currently setting up new case studies, some of them involving significant modification in tasks definition, allowing re-investigating our hypotheses about selection and manipulation techniques. We are developing a new application, based on a corridor-and-elevator scenario in order to allow a better investigation of VRE navigation issues jointly with selection techniques. The combination of both selection and navigation techniques, with intuitive transition modes from one to another, is promising and merits additional research.

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